Changes in the Aquatic Plant Community of Long Lake, Chippewa County 1986-2001 MWBC:2351400

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EXECUTIVE SUMMARY

Long Lake is an oligotrophic/mesotrophic lake with good water clarity and very good water quality. Since 1986, nutrients have increased in Long Lake; water clarity has decreased; but algae have decreased. The small watershed in relation to the size of the lake is and the natural vegetative cover in the watershed is a major factor in preserving water quality.

The aquatic plant community in Long Lake is of slightly below-average quality for Wisconsin lakes, yet Long Lake's plant community has very good species diversity. The below average quality is due to sparse plant growth. Plants were found in scattered beds, mostly limited to the 0-5ft depth zone.

Several factors could be limiting aquatic plant growth in Long Lake:
1) high-density, hard sediments (sand and rock)
2) steeply sloped littoral zone
3) limited nutrients of its oligotrophic status
4) the soft water
5) herbivory by rusty crayfish.

Management Recommendations
1) Preserve the natural landscape of forests and wetlands in the watershed to protect the quality of the water entering Long Lake.
2) Preserve and enhance the natural vegetation along the lakeshore. Much of the shoreline around Long Lake is protected by natural plant cover, but the amount of disturbed shoreline has increased since 1995. Natural shoreline needs to be replaced in areas that have been converted to cultivated lawn. Replacing shrub cover would also enhance wildlife habitat.
3) Assess septic systems along the lakeshore to insure that septic systems are not contributing nutrients that would speed the eutrophication of Long Lake.
4) Conduct studies designed to determine the impact of the rusty crayfish in Long Lake on the aquatic plant community in Long Lake.
5) Research literature regarding studies on rusty crayfish control and experiment with control methods in Long Lake
6) Preserve the sensitive areas designated on Long Lake.
7) Increase aquatic plant study transects on Long Lake to 31 by randomly placing 4 additional transects.
8) Continue water quality monitoring.

I. INTRODUCTION

Studies of the aquatic macrophytes (plants) in Long Lake were conducted August 1986, July 1989, August 1992, July 1995, July 1998 and July 2001 by Water Resources staff of the Western Central Region - Department of Natural Resources (DNR). In 1977, Environmental Resource Assessments conducted an aquatic plant survey in Long Lake (Cairns and Sorge 1978), using different methods than those used by the DNR.

The surveys were conducted as part of a Long Term Trend Monitoring Program involving 50 lakes throughout the state. The program was initiated in 1986 to provide long-term chemical and biological data on a variety of Wisconsin lakes. The lakes were selected to represent a wide range in water quality, size and amount of development. Long Lake was included in the program because it exhibited a high potential for change and because of its importance as a regional recreation resource. Aquatic plant data is collected every three years and water quality data is collected every year on the trend lakes.

Long term studies of the diversity, density, and distribution of macrophytes are ongoing and provide information that is valuable for decisions about fish habitat improvements, designation of sensitive wildlife areas, water quality improvement and aquatic plant management. Trend data can reveal changes occurring in the lake ecosystem.

Background

Long Lake is a 1052-acre groundwater drainage lake located in Chippewa County, Wisconsin. It has a maximum depth of 101 feet and a two foot concrete control structure that is owned by Chippewa County. Cedar Creek flows into the lake along the northwest shore, out of the lake along the northeast shore and eventually into Chain Lake.

The majority of Long Lake's 3930-acre watershed is undeveloped forest and wetland. There are 260 acres of wetlands adjacent to the lake. (Bernhardt 1984).

Woodland - 50%
Wetlands - 37%
Agricultural - 8%
Residential and Commercial - 3%
Parks and Camps - 1% (Bernhardt 1984).

History

Analysis of sediment cores from Long Lake record a time span of 200 years and suggest a general history of the lake (Garrison 1997). The sediment cores indicate a low rate of sedimentation into Long Lake during the early 1800's.

During the 1880's, algae production increased; soil erosion and sedimentation doubled, corresponding to the time period of logging in Long Lake's watershed. Also during that time period, extensive fires destroyed most of the homes around the shore (Garrison 1997).

During 1900-1925, the sedimentation rate decreased to levels that were slightly higher than pre-settlement (Garrison 1997).

During the 1940's, a time of intense shoreline development on Long Lake, soil erosion increased significantly and the water quality in Long Lake degraded dramatically (Garrison 1997).

The water quality started improving again in the 1980's (Garrison 1997).

Diminishing aquatic macrophyte populations became a concern of local residents during the early- to mid-1960's. While aquatic macrophytes were decreasing, residents noted increasing populations of rusty crayfish (*Orconectes rusticus*).

The rusty crayfish, a native to Illinois, Indiana, Ohio, Kentucky and Tennessee, is an exotic species in Wisconsin. This species of crayfish was likely introduced through its use as fishing bait (Lorman 1980). Plant material makes up a major portion of the rusty crayfish diet (Magnuson, et. al. 1975). Since, *Orconectes rusticus* has a higher metabolic rate than other species of crayfish, it can eat twice as much plant biomass as some of the native crayfish (Gunderson 1995). Crayfish biomass greater than $9g/m^2$ can reduce macrophyte biomass by 64% and greater than $140g/m^2$ can eliminate all macrophytes (Miller et. al).

In 1974, a study was sponsored by the National Science Foundation and the Wisconsin Department of Natural Resources to assess the role of crayfish in the decline of aquatic plants. The crayfish study in Long Lake (Magnuson et. al. 1975) indicated:

1) Rusty crayfish density in Long Lake was high, compared to other lakes with rusty crayfish populations.
2) The mean density of rusty crayfish in Long Lake was 51 crayfish per meter^2 on rock substrate and 4 crayfish per meter^2 on sand substrate. (Rusty crayfish in Long Lake would need to be in the size range of only 2.7-35 grams each to completely eliminate all vegetation in the area in which they occurred.)
3) There was an inverse relationship between crayfish abundance and macrophyte density. Sites in Long Lake with high crayfish densities lacked macrophytes. Areas of the lake in which crayfish were less abundant supported more vegetation (Magnuson et. al. 1975).

The rusty crayfish dominated the crayfish community in Long Lake, almost to the total exclusion of native crayfish. The 1974-78 crayfish population in Long Lake was estimated at 5.2 million crayfish, with a yearly production of 6700 kg of crayfish tissue per year (dry weight) (Magnuson et. al. 1975).

The sparse condition of the vegetation in Long Lake raised the concern that the DNR aquatic plant sampling in 1986-1998 was inadequate to characterize the community. Two studies were conducted to assess the adequacy of the DNR sampling.

1) In 1996, calculations of sampling adequacy indicated that, based on "no vegetation" as the most frequent "species", 31 transects would be necessary to be 95% confident that the true frequency of "no vegetation" was 76%-86% (Konkel 1999). The Long Term Trend Study designed in 1986 placed 27 transects on Long Lake.
2) In 1998, 20 additional random sites were placed in the depth zone that supported the greatest amount of vegetation. Non-parametric t-tests indicated that there was no significant difference between the 1986 fixed sites and the additional random sites in regard to
    a) the number of vegetated sites
    b) the number of non-vegetated sites
    c) the number of species per site
    d) the total density of plants per sites

It is possible to be confident in the "no vegetation" frequency and overall abundance of aquatic macrophytes (Konkel 1999).

In 2001, a Sensitive Areas Study was conducted on Long Lake by staff of the DNR. Sites that are most important to the habitat and water quality values of Long Lake were identified and mapped. Recommendations for protecting each of the sensitive areas was outlined (Konkel 2001).

II. METHODS

Field Methods

The same study design and transects were used for the 1986-2001 macrophyte studies and was based primarily on the rake-sampling method developed by Jessen and Lound (1962). Twenty-seven equal-distance transects were placed perpendicular to the shoreline with the first transect being randomly placed (Appendices).

One sampling site was randomly located in each depth zone (0-1.5ft, 1.5-5ft, 5-10ft, and 10-20ft) along each transect. Using a long-handled, steel, thatching rake, four rake samples were taken at each sampling site. The four samples were taken at each quarter of a 6-foot square quadrat. The aquatic plant species that were present on each rake sample were recorded. Aquatic macrophytes recorded included vascular plants and algae that have morphologies similar to vascular plants, such as muskgrass and nitella. The presence of filamentous algae was also noted.

Each species was given a density rating (0-5), at each sampling site, based on the number of rake samples on which it was present.
A 1 indicates that a species was present on one rake sample.
A 2 indicates that a species was present on two rake samples.
A 3 indicates that a species was present on three rake samples.
A 4 indicates that it was present on all four rake samples.
A 5 indicates that the species was abundantly present on all rake samples at that sampling site.

The sediment type at each sampling site was recorded. Visual inspection and periodic samples were taken between transect lines in order to record the presence of any species that did not occur at the sampling sites. Specimens of all plants present were collected and saved in a cooler for later preparation of voucher specimens. Nomenclature was according to Gleason and Cronquist (1991).

The type of shoreline cover was recorded at each transect. A section of shoreline, 50 feet on either side of the transect intercept with the shore and 30 feet deep, was evaluated. The estimated percentage of cover types within this 100' x 30' rectangle was recorded.

Data Analysis

Data for each year was analyzed separately and compared. The percent frequency of occurrence of each species was calculated (number of sampling sites at which it occurred / total number of sampling sites) (Appendices I-VI). Relative frequency was calculated (the number of occurrences of a species / sum of all species occurrences) (Appendices I-VI).

The mean density was calculated for each species (sum of a species' density ratings / number of sampling sites) (Appendices VII-XII). Relative density was calculated (the sum of the density ratings of a species / sum of all plant densities) (Appendices VII-XII). A "mean density where present" was calculated for each species (sum of a species' density ratings / number of sampling sites at which that species occurred) (Appendices VII-XII).

The relative frequency and relative density were summed to obtain a dominance value (Appendices XIII-XVIII).

Simpson's Diversity Indices were calculated for each sampling year (Appendices I-VI). Each sampling year was compared by a Coefficient of Community Similarity.

An Aquatic Macrophyte Community Index (AMCI), developed for Wisconsin lakes, was applied to Long Lake. Six parameters that characterize the aquatic macrophyte community (Table 8) are measured and the data for each is converted to a value 0 - 10 as outlined by Weber et. al. (1995).

The Average Coefficient of Conservatism and Floristic Quality Index was calculated for each sampling year to measure disturbance in the plant community (Nichols 1998). A coefficient of conservatism is an assigned value, 0-10, the probability that a species will occur in a relatively undisturbed habitat; the Average Coefficient of Conservatism is the mean of the coefficients for each species found in a lake; Floristic Quality (I) is calculated from the Average Coefficient of Conservatism.

III. RESULTS

PHYSICAL DATA

Many physical parameters impact the macrophyte community. Water quality (concentration of nutrients and algae, water clarity, hardness) influences the macrophyte community as the macrophyte community can in turn modify these parameters. Lake morphology, sediment composition and shoreland use also impact the macrophyte community.

WATER QUALITY - The trophic state of a lake is an indication of its water quality. Phosphorus concentration, chlorophyll concentration, and water clarity data are collected and combined to determine the trophic state.

Oligotrophic lakes have low nutrients and biomass.

Eutrophic lakes have high nutrients and biomass and often experience algal blooms.

Mesotrophic lakes are intermediate in nutrient and biomass.

Nutrients

Phosphorus is the limiting nutrient in many Wisconsin lakes. This means that the addition or reduction of phosphorus is the nutrient that will have the most impact on water quality. Therefore, phosphorus concentrations are measured as an indication of the nutrient status of a lake. The phosphorus concentrations in Long Lake have remained within the oligotrophic/mesotrophic range (Figure 1).

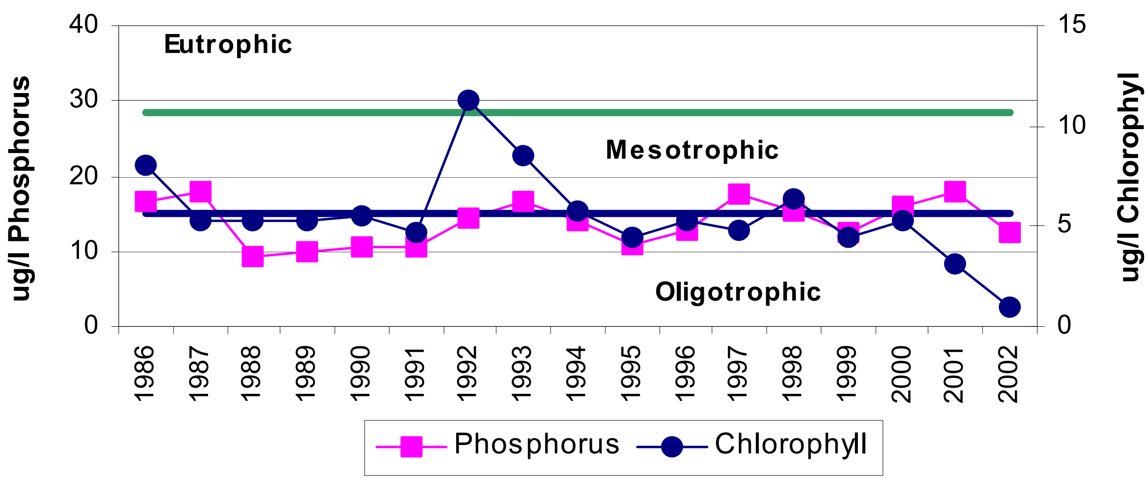


Figure 1. Mean summer phosphorus and chlorophyll in Long Lake, 1986-2002.

Algae

Algae cells contain chlorophyll, so chlorophyll concentrations are measured to indicate algae concentrations. Chlorophyll in Long Lake has also remained in the oligotrophic/mesotrophic range during most of the study years.

In 1992, there was unusually high chlorophyll (Figure 1). Chlorophyll decreased to the lowest concentrations recorded in 2001-2002.

Water chemistry data was collected on Long Lake by Lou Frase, a volunteer in the Self Help Lake Monitoring Program. Lou started collecting water chemistry data in 2001.

The volunteer data is valuable in that it is collected more frequently, augments the data points collected by the DNR and includes sampling in an additional basin. Data was collected in Long Lake and in the southeast basin that is referred to as Herde Lake.

The Long Lake volunteer data was similar to the DNR data, except the phosphorus data was slightly lower, in the oligotrophic range (Table 1). The Herde Lake basin data is very similar to the main lake basin data, except the Herde Lake basin exhibits a slightly higher phosphorus concentration, in the mesotrophic range (Table 1).

Table 1. Trophic Status, 2001

	Quality Index	Phosphorus ug/l	Chlorophyll ug/l	Secchi Disc ft.
Oligotrophic	Excellent	<1	<1	> 19
	Very Good	1-10	1-5	8-19
Mesotrophic	Good	10-30	5-10	6-8
	Fair	30-50	10-15	5-6
Eutrophic	Poor	50-150	15-30	3-4
Hypereutrophic	Very Poor	>150	>30	>3
Long Lake - DNR data, 2001	Good	18	3.2	7.4
Long Lake - Volunteer data 2001	Good	10.3	5.6	9.9
Herde Lake - Volunteer data 2001	Good	12.7	5.3	7.8

After Lillie & Mason (1983) & Shaw et. al. (1993)

Water Clarity

The availability of light is a critical factor for plant growth (Chambers and Kalff 1985, Duarte et. al. 1986, Kampa 1994). Aquatic macrophytes cannot survive when they receive less than 1-2% of the available surface light. Water clarity is impacted by a combination of color (dissolved materials) and turbidity (suspended materials). A Secchi Disc measures the combined effects of color and turbidity.

Long Lake has had good water clarity and the values have remained in the oligotrophic range during the study period.

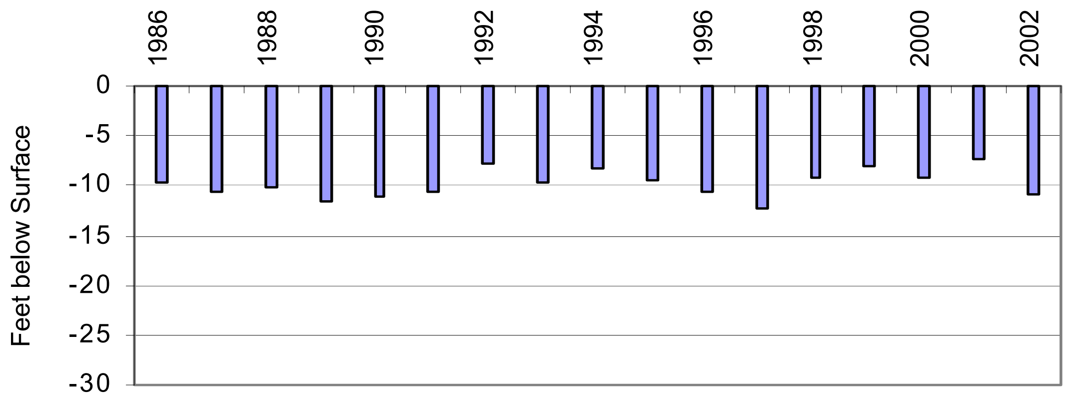


Figure 2. Water clarity (Secchi Disc) in Long Lake, 1986-2001.

The combination of phosphorus (nutrient), chlorophyll (algae) and water clarity data places Long Lake in the oligotrophic/mesotrophic range with good water clarity and very good water quality.

Water clarity data was also collected on Long Lake by volunteers in the Self Help Lake Monitoring Program. Gloria Berres collected clarity data in 1990; Pete Scolaro collected clarity data 1994-1998; Pete Scolaro and Lou Frase collected clarity data in 1999; Lou Frase has continued collecting clarity data since 2000.

Volunteer water clarity data for Long Lake was similar to the DNR data, within the range of good water clarity. The year-to-year variations were less extreme in the volunteer data. This is likely because the volunteer data is collected more often and unusual events are averaged out (Figure 3).

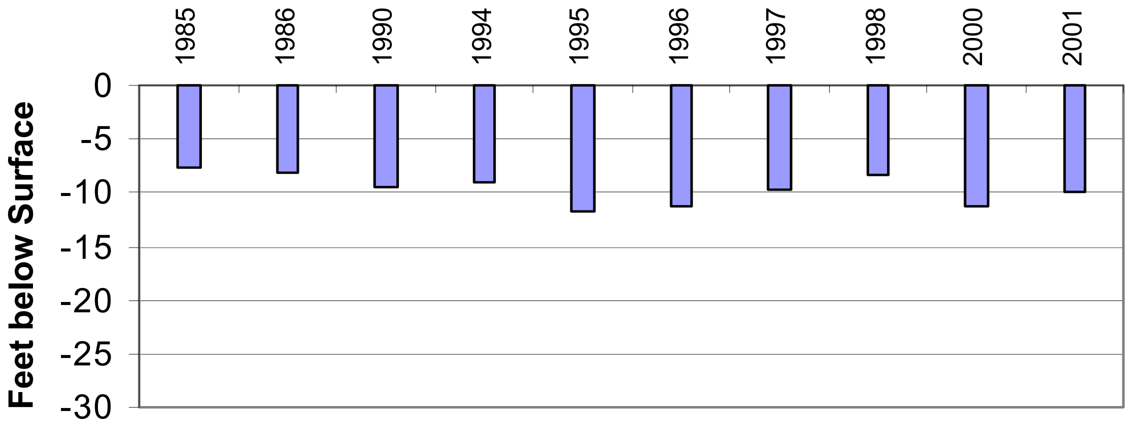


Figure 3. Mean summer water clarity in Long Lake, volunteer data.

Water clarity data collected on Herde Lake by volunteer monitors indicate that Herde Lake also has good, but slightly lower clarity. The year-to-year variations are similar to the Long Lake data (Figure 4).

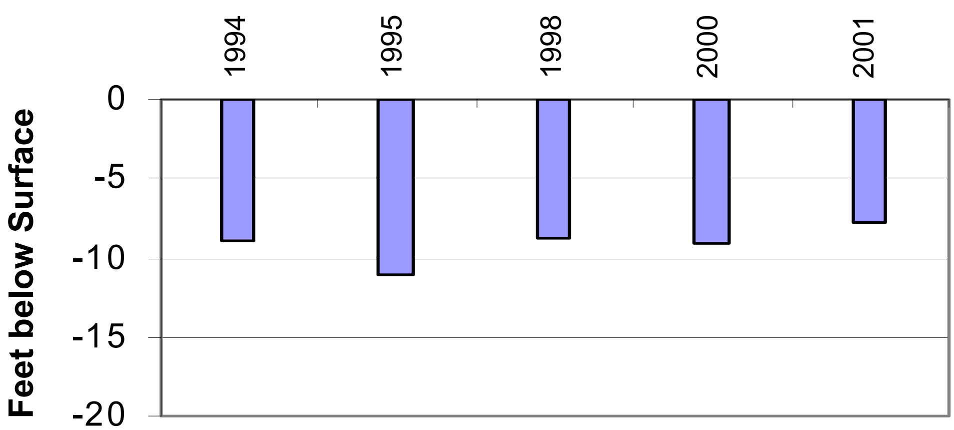


Figure 4. Mean summer water clarity in Herde Lake

Data collected at the same time of the year was averaged to show the change in water clarity during the year in Long Lake (Figure 5) and in the southeast basin that is referred to as Herde Lake (Figure 6). In both areas of the lake, water clarity is greatest in the spring and decreases during the summer as the water warms and algae start reproducing.

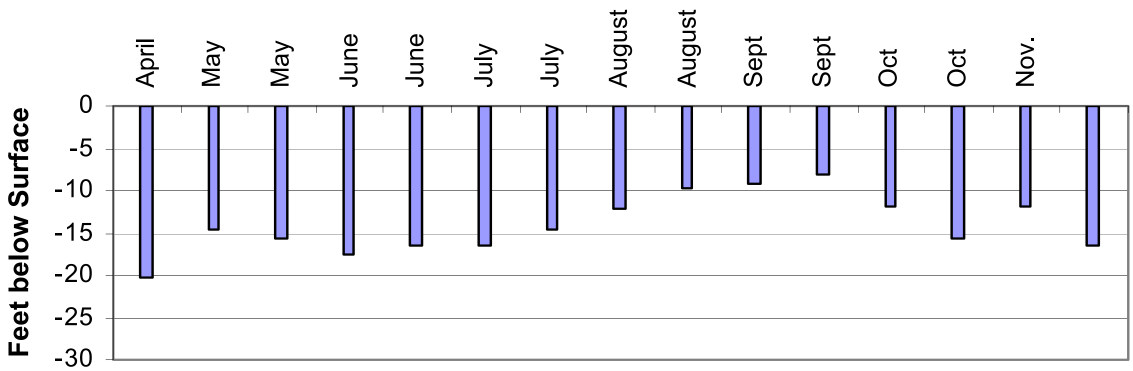


Figure 5. Change in mean water clarity during the season, Long Lake.

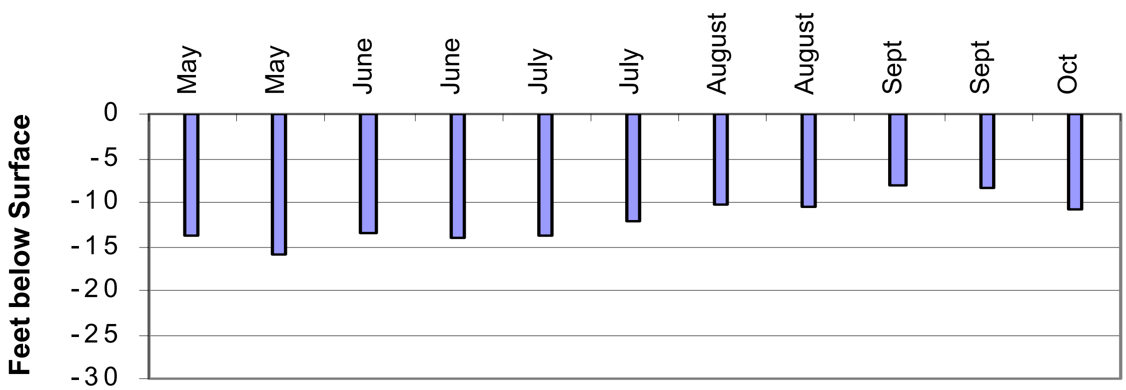


Figure 6. Change in mean water clarity during the season, Herde Lake.

Hardness

Hardness is affected by the type of minerals in the soil and bedrock and how often the water comes in contact with the soil/bedrock. The water hardness in Long Lake, as measured by the amount of calcium carbonate in a volume of water, during the 17-year study has varied from 46 to 62 mg/l $CaCo_3$. Water with hardness values of 0-60mg $CaCO_3$/l is considered soft (Shaw et. al. 1993). Soft water lakes such as Long Lake have a high sensitivity to the effects of acid rain and tend to have less plant growth.

Lake Morphometry

The morphometry of a lake impacts the distribution of aquatic macrophytes. Duarte and Kalff (1986) found that the slope of the littoral zone accounted for 72% of the observed variability in the growth of submergent vegetation. Steep slopes often inhibit the rooting success of macrophytes; gentle slopes support a broad zone of potential plant growth (Engel 1985).

About 40% of the littoral zone in Long Lake is steeply-sloped, the southwest end of Long Lake is the steepest (Appendices). This limits the area suitable for colonization by aquatic plants. More gradually sloped lake bottoms in the rest of the lake could be more conducive to plant growth.

Sediment composition

Sand was the dominant sediment at the sample sites (Table 2) and occurred throughout the lake, most frequently in the deeper zones.

Rock and gravel mixtures were also common and dominant in the 0-1.5ft depth zone; sand and rock mixtures were common in the 1.5-5ft depth zone (Table 2).

Table 2. Sediment Composition 2001

Sediment		0.1.5ft	1.5-5ft	5-10ft	10-20ft	Overall
Hard Sediments	Sand	15%	48%	38%	63%	41%
	Rock/gravel	59%	11%	27%	7%	26%
	Sand/Rock	11%	22%	8%		10%
Mixed Sediments	Sand/silt			8%	4%	3%
	Sand/peat	4%	4%			1%
Soft Sediments	Peat	11%	11%	15%	18%	14%
	Silt		4%	4%	7%	4%

Shoreline Land Use

Land use activities on the shore strongly impact the aquatic plant community. Practices on shore can directly effect the plant community through increased sedimentation from erosion, increased nutrient levels from fertilizer run-off and soil erosion and increased toxics from farm and urban run-off.

Wooded cover was the most frequently encountered on-shore land use in 2001 and the land use with the highest mean coverage at the transects in Long Lake (Table 3). Shrub and native herbaceous cover commonly occurred at the transects.

Disturbed shoreline commonly occurred; cultivated lawn was commonly encountered; hard structure was found at 15% of the transects (Table 3).

Table 3. Shoreline Land Use, 1995-2001

Cover Type		Mean Coverage		Frequency of Occurrence
		1995	2001	2001
Natural Shoreline	Wooded	53%	56%	85%
	Shrub	21%	12%	33%
	Native Herbaceous	13%	12%	44%
Disturbed Shoreline	Cultivated Lawn	9%	13%	33%
	Hard Structure	2%	2%	15%
	Bare Soil	1%	1%	4%
	Rip-rap		1%	14%
	Road	1%	3%	7%

Comparison of the 1995 and 2001 shoreline use data indicates that coverage of shrub growth at the shoreline has decreased. This decrease in shrub cover has been accompanied by an increase in the coverage of cultivated lawn (Table 3).

Some type and amount of natural shoreline was found at all transects; the coverage of natural shoreline decreased from 87% coverage in 1995 to 80% in 2001.

Some type of disturbed shoreline was encountered at 44% of the sites and had a mean coverage of 20% in 2001. This is an increase from 13% coverage in 1995 (Table 3).

MACROPHYTE DATA

SPECIES PRESENT

A total of 37 different species of macrophytes have been found during the 1986-2001 studies: 18 emergents species, 6 floating leaf species, and 13 submergent species (Table 4).

No endangered, threatened or non-native species were found. One special concern species was found: *Potamogeton vaseyi.*

Table 4. Long Lake Aquatic Plant Species, 1986-2001

Scientific Name	Common Name	I. D. Code
Emergent Species		
1) *Alnus incana* (L.) Moench.	tag alder	alnin
2) *Asclepias incarnata* L.	swamp milkweed	ascin
3) *Bidens discoidea* (T. & G.) Britton	bur marigold	biddi
4) *Carex* sp.	sedge	carsp
5) *Chamaedaphne calyculata* (L.) Moench.	leatherleaf	chaca
6) *Decodon verticillatus* (L.) Elliott.	swamp loosestrife	decve
7) *Dulichium arundinaceum* (L.) Britton	three-way sedge	dular
8) *Eleocharis palustris* L.	creeping spikerush	elepa
9) *Equisetum fluviatile* L.	water horsetail	equfl
10) *Iris versicolor* L.	northern blue flag	irive
11) *Pontederia cordata* L.	pickerelweed	ponco
12) *Potentilla palustris* (L.) Scop.	marsh cinquefoil	potpa
13) *Sagittaria latifolia* Willd.	common arrowhead	sagla
14) *Sagittaria* sp.	arrowhead	sagsp
15) *Scirpus americanus* Pers.	Olney's threesquare	sciam
16) *Scirpus validus* Vahl.	softstem bulrush	sciva
17) *Typha angustifolia* L.	narrow-leaf cattail	typan
18) *Typha latifolia* L.	broadleaf cattail	typla
Floating leaf Species		
19) *Brasenia schreberi* J. F. Gmelin.	watershield	brasc
20) *Lemna minor* L.	small duckweed	lemmi
21) *Lemna trisulca* L.	forked duckweed	lemtr
22) *Nuphar variegata* Durand.	bull-head pond lily	nupva
23) *Nymphaea odorata* Aiton.	white water lily	nymod
24) *Spirodela polyrhiza* (L.) Schleiden.	great duckweed	spipo
Submergent Species		
25) *Ceratophyllum demersum* L.	coontail	cerde
26) *Elodea canadensis* Michx.	common waterweed	eloca
27) *Myriophyllum tenellum* Bigelow.	dwarf water milfoil	myrte
28) *Najas flexilis* (Willd.) Rostkov & Schmidt.	slender naiad	najfl
29) *Potamogeton amplifolius* Tuckerman.	large-leaf pondweed	potam
30) *Potamogeton epihydrus* Raf.	ribbon-leaf pondweed	potep
31) *Potamogeton foliosus* Raf.	leafy pondweed	potfo
32) *Potamogeton gramineus* L.	variable-leaf pondweed	potgr
33) *Potamogeton pusillus* L.	small pondweed	potpu
34) *Potamogeton robbinsii* Oakes.	fern pondweed	potro
35) *Potamogeton vaseyi* Robbins.	Vasey's pondweed	potva
36) *Potamogeton zosteriformis* Fern.	flatstem pondweed	potzo
37) *Vallisneria americana* L.	water celery	valam

FREQUENCY OF OCCURRENCE

The frequency of macrophyte species in Long Lake varied among the survey years. The most frequent species during one sample year sometimes did not occur at any sample sites in another year. The overall low occurrence and sparse growth of macrophytes is probably the reason for this variability.

Nuphar variegata was the most frequent species in 1986 (1.8%) and has remained at stable frequencies, except for a disappearance from sample sites in 1989 and a decrease (0.9%) in 1995 (Table 5).

Ceratophyllum demersum, Eleocharis palustris and *Potamogeton amplifolius* became the most frequent species in 1989 (1.8%). *E. palustris* is an emergent species. The two submergent species increased in frequency in 1992 and decreased in 1995 and 1998. *C. demersum* increased frequency in 2001, but *P. amplifolius* disappeared from the sample sites (Table 5).

Pontederia cordata was the most frequent species in 1992 (5.6%) and 1998 (2.8%), but occurred at lower frequencies (0.9%-1.9%) other years.

Elodea canadensis and *Potamogeton epihydrus* were the most frequent species in 1995 (3.7%), but decreased to lower frequencies in (0-1.9%) in 1998 and 2001 (Table 5).

Scirpus validus was the most frequent species in 2001 (4.7%), this species had occurred at lower frequencies in previous studies.

Table 5. Frequencies of Prevalent Macrophyte in Long Lake 1986-2001.

Species	1986	1989	1992	1995	1998	2001
Ceratophyllum demersum	0.9%	1.8%	2.8%	1.8%	0.9%	1.9%
Eleocharis palustris		1.8%			0.9%	0.9%
Elodea canadensis			2.8%	3.7%	0.9%	
Nuphar variegata	1.8%		1.8%	0.9%	1.8%	1.9%
Pontederia cordata	0.9%	0.9%	5.6%	0.9%	2.8%	1.9%
Potamogeton amplifolius		1.8%	3.7%	1.8%	1.8%	
Potamogeton epihydrus		0.9%	3.7%	3.7%	1.8%	1.9%
Scirpus validus	0.9%	0.9%	1.8%			4.7%

The occurrence of filamentous algae has also been cyclic (Figure 7). The lowest occurrence of filamentous algae was in 1989 (4%) and the highest occurrence of filamentous algae was in 1995 (17%) (Figure 7).

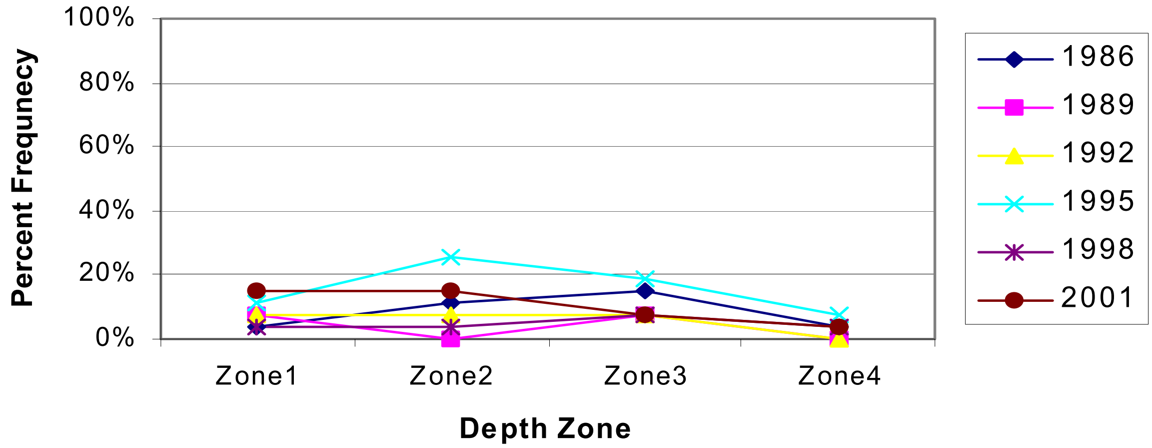


Figure 7. Occurrence of filamentous algae in Long Lake by depth zone, 1986-2001.

DENSITY

The mean density of macrophytes in Long Lake has varied, but all macrophyte densities have been low (Appendix VII-XII). The highest mean density of any species was *Pontederia cordata* (0.15 on a scale of 0-5) in 1992.

"Density where present" measures how dense of a growth form a species exhibits. A species may have a low frequency and low mean density over the lake, but where it does occur, may exhibit a dense form of growth. Different species have exhibited dense growth forms ("density where present" > 2.5) in different year (Figure 8). Many species have cycled between dense and sparse growth forms from year to year. This could indicate that there is a real change in a species growth, or that the transects are shifting slightly and recording different plant beds in different years.

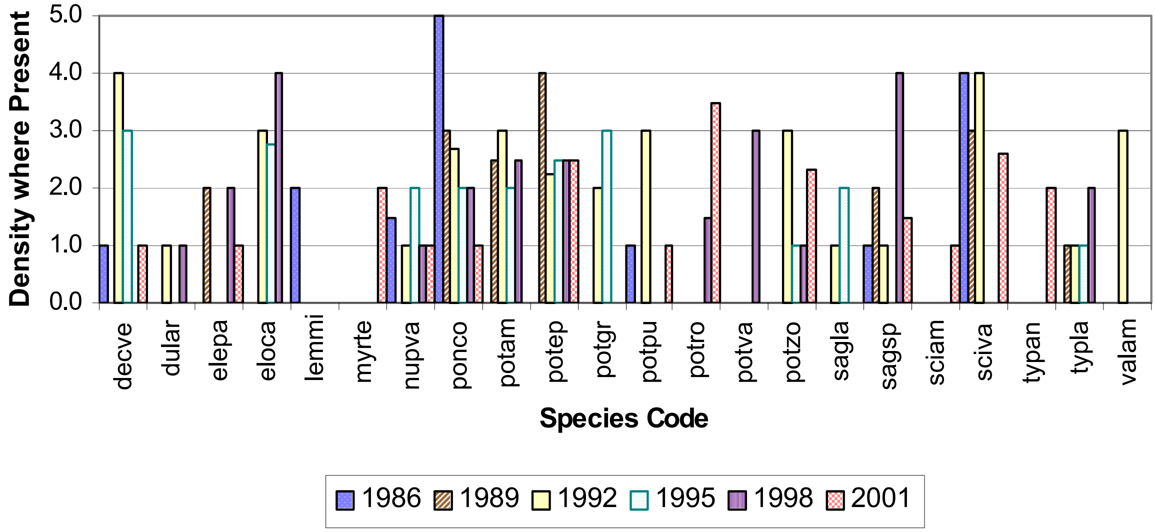


Figure 8. "Density where present" of aquatic plant species in Long Lake, 1986-2001

DOMINANCE

The dominance value illustrates the dominance a species within the community. Any discussion of the dominance of macrophyte species in Long Lake must be with the understanding that overall frequency and density of aquatic plants in Long Lake is low and small changes in the frequency or density of species can change the dominance of individual species.

The dominant species have varied over the study years (Figure 9). *Nuphar variegata* and *Pontederia cordata* were the dominant species in 1986. *Potamogeton amplifolius* was the dominant species in 1989; *Pontederia cordata* was again dominant in 1992; *Elodea canadensis* was the dominant species in 1995; *P. cordata* was the dominant species again in 1998; and *Scirpus validus* was the dominant species in 2001.

Figure 9. Dominance of prevalent macrophyte species in Long Lake, 1986-2001.

DISTRIBUTION

Aquatic plant growth in Long Lake has occurred at depths up to 15 feet, in scattered beds. The littoral zone has had sparse macrophyte growth. Aquatic plants occurred at only 6.5%-15% of all sampling sites in 1986- 2001. Most plant growth is in the north end of the lake and in the southeast section, referred to as Herde Lake. The greatest percent of sample sites with vegetation occurred in 2001 (Figure 10).

The highest percent of vegetated sites has varied between the 0-1.5ft and the 1.5-5ft depth zones in different study years (Figure 8). The frequency of vegetation in the 0-1.5ft depth zone has varied the most. The 1.5-5ft depth zone has had consistent frequency of vegetation, except during 1986, when the frequency of vegetation in this zone was very low. The 5-20ft depth zone has had virtually no vegetation during all study years.

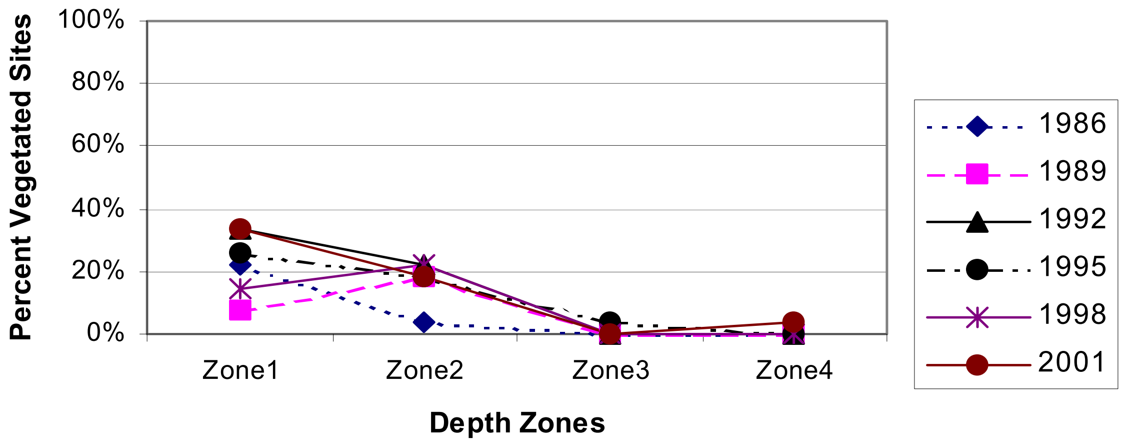


Figure 10. Percentage of littoral zone that is vegetated.

The zone with the highest total occurrence (Figure 11) and total density (Figure 12) of aquatic plant growth varied between the first two depth zones during the study years. The highest total occurrence and density of plant growth was in 1992 and the lowest in 1986.

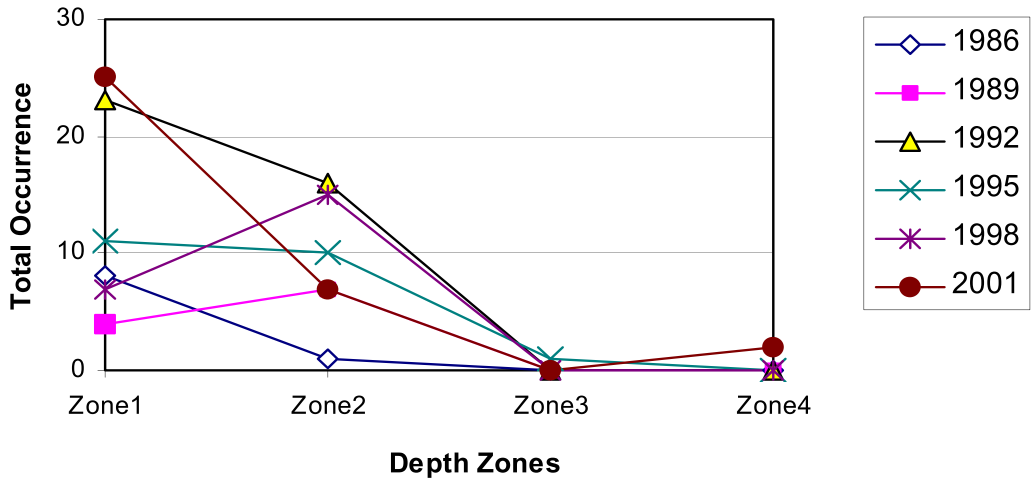


Figure 11. Total occurrence of macrophytes by depth zone.

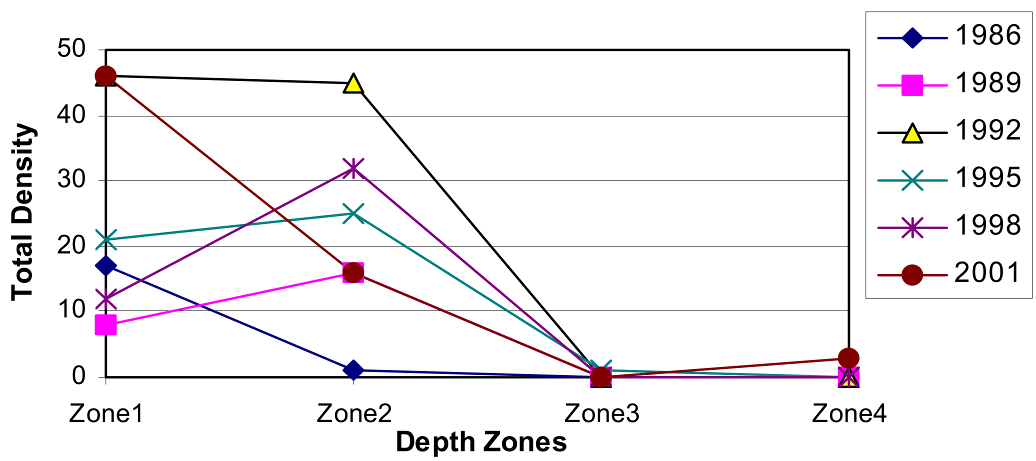


Figure 12. Total density of macrophytes by depth zone.

Macrophyte distribution patterns have varied. Maps drawn in conjunction with macrophyte surveys provide an approximation of macrophyte colonization (Konkel 1999). The most recent map (Figure 13) indicates more plant beds of smaller sizes than the earliest map in 1939 (Konkel 1999). Macrophyte beds seem to be cycling between periods of sparse growth and periods of even sparser growth. This cycling may be due to natural phenomena or human-induced disturbances (Konkel 1999).

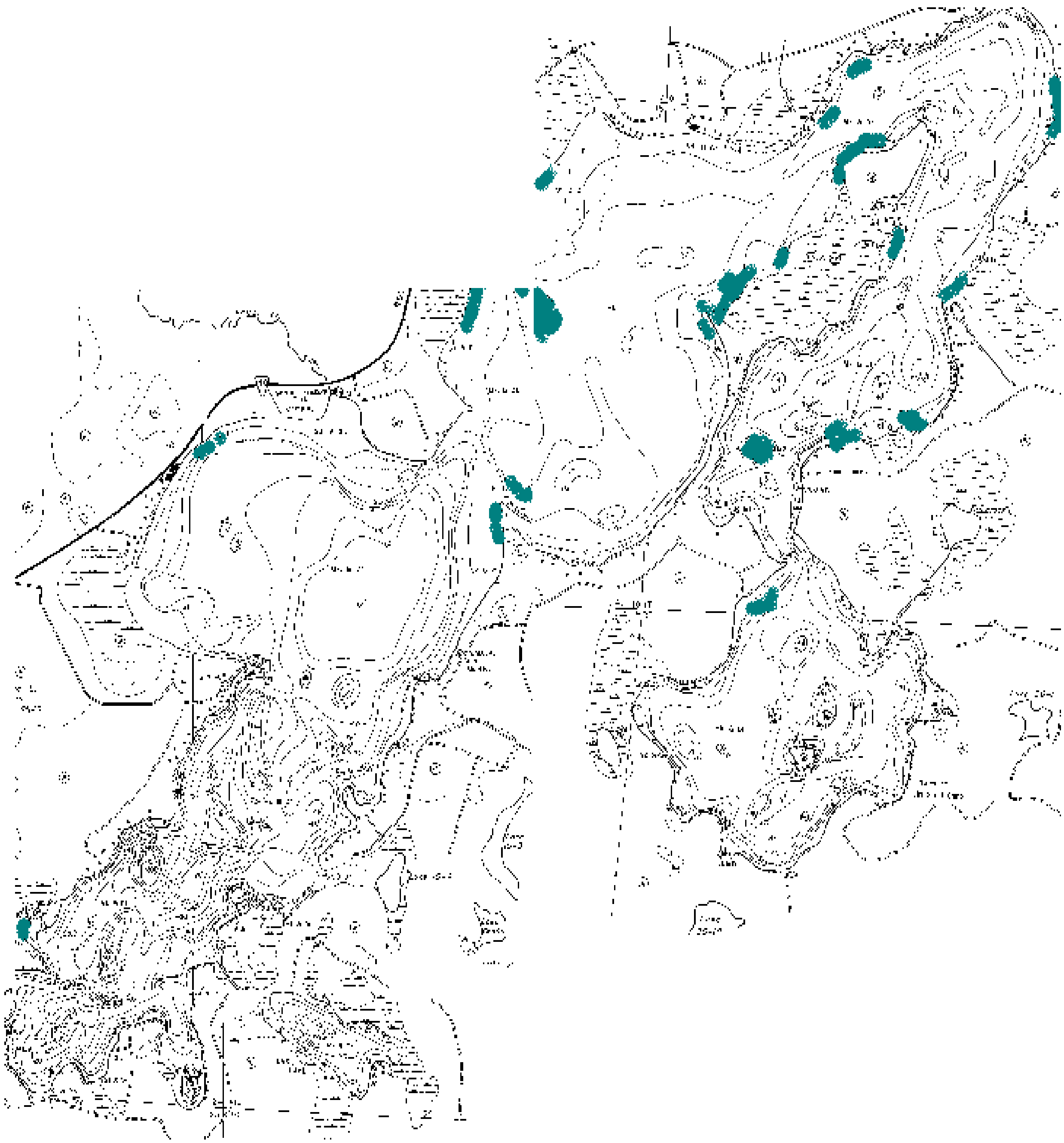


Figure 13. Distribution of plant beds in 2001.

The predicted maximum rooting depth can be calculated from water clarity data (Dunst 1982). During 1986-1998, the actual maximum rooting depth had remained constant, 3-3.5 feet, and much less than the predicted maximum rooting depth (Figure 14). *Elodea canadensis, Nuphar variegata, Pontederia cordata, Potamogeton* *amplifolius, P. epihydrus* and *P. zosteriformis* had been recorded at the maximum depth of 3-3.5 feet in 1986-1998.

In 2001, the maximum rooting depth of plant growth increased substantially to 15 feet; *Myriophyllum tenellum* and *Sagittaria* sp., small rosette species, were recorded at 15 feet. The maximum rooting depth in 2001 was in the predicted range of 11.7 to 17.7 feet, based on water clarity (Figure 14).

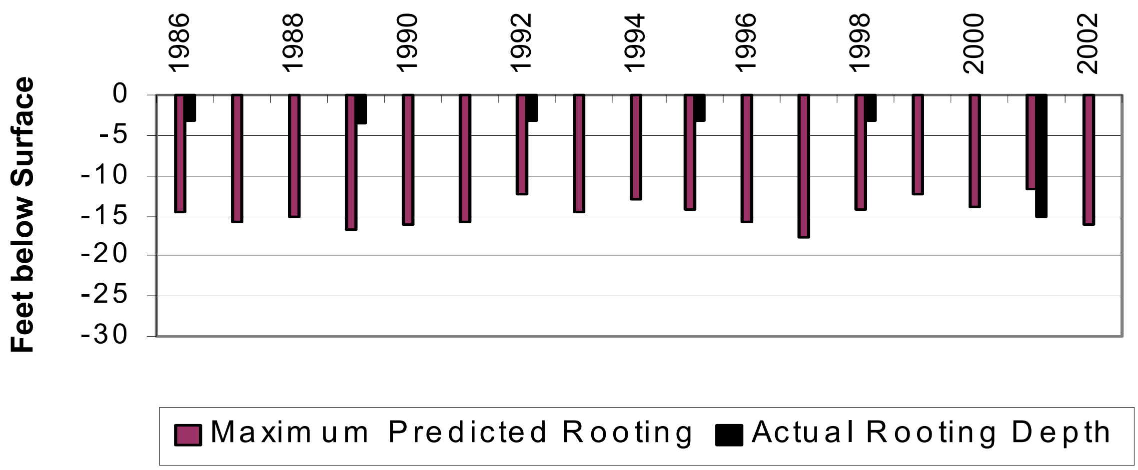


Figure 14. Maximum rooting depth of aquatic plants in Long Lake, 1986-2002.

SEDIMENT COMPOSITION

Some aquatic plants depend on the sediment in which they are rooted for their nutrients. The richness or sterility, texture and density of the sediment will determine the type and abundance of species that can survive in a location.

The availability of mineral nutrients for plant growth is highest in sediments of intermediate density such, as silt (Barko and Smart 1986), but silt occurred infrequently (Table 6).

Sand sediments, which were the dominant sediments in Long Lake, supported some vegetation (11% of the sand sites were vegetated) (Table 6). Rock sediments were also commonly encountered and infrequently supported vegetation.

Rock, sand and gravel sediments can be nutrient limiting due to their high density (Barko and Smart 1986).

Peat sediments were commonly vegetated (Table 6), although peat sediments can be too flocculent for effective rooting of vegetation.

Sand and peat mixtures supported the highest percentage of vegetation (100% vegetated). The sand mixed with the peat may add enough firmness to provide a more favorable rooting substrate. However, peat and sand mixtures occurred very rarely (1% of the sites had peat/sand mixtures) (Table 6).

Table 6. Macrophyte Occurrence at Sediment Types, 2001.

Sediment Category		Frequency of Occurrence of Sediment	% Vegetated
Hard Sediments	Rock	26%	7%
	Sand/rock	10%	9%
	Sand	41%	11%
Mixed Sediments	Sand/silt	3%	
	Sand/peat	1%	100%
	Rock/silt		
Soft Sediments	Peat	14%	27%
	Silt	4%	

MACROPHYTE COMMUNITY

The Coefficients of Community Similarity indicate that the macrophyte community in Long Lake has changed significantly (Table 7). The aquatic plant community appeared to be undergoing significant change each year during 1986-2001, with no community being more than 66% similar to the previous community and some communities only 38% similar to the previous community.

The changes during the study years have accumulated and has resulted in the most recent 2001 plant community being only 42% similar to the community of 1986 (Table 7).

Table 7. Coefficients of Community Similarity.

Years compared	Coefficient	Percent Similarity*
1986-89	0.3838	38%
1989-92	0.4876	49%
1992-95	0.6601	66%
1995-98	0.4712	47%
1998-2001	0.4613	46%
1986-2001	0.4185	42%

* - Communities that are less than 75% similar are considered significantly different.

Several parameters and indices can be used to assess the macrophyte community and determine what changes have occurred within the community.

In Long Lake, several parameter increased from 1986-1992, declined in 1995 and subsequently increased through 1998-2001: number of species recorded, diversity index, percent of the littoral zone vegetated, percent cover of emergent species and

Floristic Quality (measuring disturbance in the community, discussed later) (Table 8).

Table 8. Changes in the Macrophyte Community.

	1986	1989	1992	1995	1998	2001	Maximum Change	%Change 1986-2001
Number of Species	8.0	8.0	17.0	11.0	16.0	18.0	10	125.0%
Maximum Rooting Depth	3.0	3.5	3.0	3.0	3.5	15.0	12	400.0%
% of Littoral Zone Vegetated	6.5	6.5	13.9	12.0	9.3	15.0	8.5	130.8%
%Sites/Emergents	2.8	3.7	9.3	4.6	5.6	9.3	6.5	232.1%
%Sites/Free-floating	1.9	1.9	2.8	1.9	0.9	0.9	1.9	-52.6%
%Sites/Submergent	0.9	1.9	6.5	7.4	4.6	5.6	6.5	522.2%
%Sites/Floating-leaf	1.9	0.0	1.9	0.9	1.9	0.9	1.9	-52.6%
Simpson's Diversity Index	0.86	0.86	0.92	0.88	0.93	0.93	0.07	8.1%
Floristic Quality Index	17.32	16.26	24.75	18.97	25.00	26.87	10.61	55.1%

The maximum rooting depth in Long Lake had remained fairly stable, until a dramatic increase in 2001. Two small rosette/turf species were recorded at depths of 15 feet in 2001 (Table 8).

The aquatic plant community in 1986-89 appeared to be at its lowest level. The fewest number of species, the smallest percent of the littoral zone vegetated, the smallest percent coverage of emergent species and submergent species, the lowest diversity and the lowest floristic quality (highest disturbance) occurred during 1986-1989 (Table 8).

The aquatic plant community in 2001 was characterized by the greatest number of species, the deepest rooting depth, the highest percentage of the littoral zone vegetated, the highest species diversity, the highest floristic quality and the greatest coverage of emergent species (Table 8).

Overall, all parameters had increased between 1986 and 2001, except the coverage of floating-leaf and free-floating species has decreased. The coverage of submergent species increased the most between 1986 and 2001, a five-fold increase. Simpson's Diversity indices in Long Lake increased from a good diversity in 1986 to a very good diversity in 2001 (Table 8).

According to the Aquatic Macrophyte Community Index (AMCI), the quality of the aquatic community in Long Lake has been improving and is of nearly of average quality (38) for Wisconsin lakes (Table 9). The maximum AMCI value is 60; the average is 40.

Table 9. Aquatic Macrophyte Community Index Values for Long Lake, 1986-2001.

	1986	1989	1992	1995	1998	2001
Maximum Rooting Depth	0	2	0	0	2	8
% Littoral Zone Vegetated	2	2	2	2	2	4
Simpson's Diversity Index	9	9	10	9	10	10
Relative Frequency of Submersed Species	4	6	6	8	6	4
Relative Frequency of Sensitive Species	2	8	8	8	10	6
# of Taxa (reduced by exotic)	2	2	6	4	6	6
Total	19	29	32	31	36	38

The sparse colonization of aquatic vegetation in the littoral zone and low ratio of submergent vegetation are limiting the quality of the aquatic plant community (Table 9).

The Average Coefficient of Conservatism for the Long Lake aquatic plant community was above the mean for Wisconsin lakes in 1986, decreased to below the mean in 1989, and increased to above the mean in 1992-2001 (Table 10). However, compared to lakes in the Northern Lakes and Forest Region, Long lake was below the mean in 1986, decreased into the lowest quartile in 1989, below the mean in 1992, decreased into the lowest quartile again in 1995 and below the mean in 1998-2001. (Table 10).

This indicates that the plant community in Long Lake has been cycling in its disturbance tolerance, likely due to a fluctuating amount of disturbance within Long Lake.

Table 10. Floristic Quality and Coefficients of Conservatism of Long Lake, Compared to Wisconsin Lakes and Northern Wisconsin Lakes.

	(C) Average Coefficient of Conservatism †	(I) Floristic Quality ‡
Wisconsin Lakes	5.5, 6.0, 6.9*	16.9, 22.2, 27.5*
NLFL	6.1, 6.7, 7.7*	17.8, 24.3, 30.2*
Long Lake, 1986-2001		
1986	6.13	17.32
1989	5.75	16.26
1992	6.19	24.75
1995	6.00	18.97
1998	6.25	25.00
2001	6.33	26.87

* - upper limit of lower quartile, mean and lower limit of upper quartile
The North Lakes and Forest Region (NLFL) is the region in which Long Lake is located.

† - Average Coefficient of Conservatism for all Wisconsin lakes ranged from a low of 2.0 (the most disturbance tolerant) to a high of 9.5 (least disturbance tolerant).

‡ - The lowest Floristic Quality in Wisconsin lakes was 3.0 (farthest from an undisturbed condition) and the high was 44.6 (closest to an undisturbed condition).

The Floristic Quality Index of the plant community in Long Lake followed the same fluctuating pattern as seen in the Average Coefficients of Conservatism. Compared to lakes in the Northern Lakes and Forest Region, Long Lake was in the lowest quartile n 1986-1989, increased to the upper quartile in 1992, dropped to below the mean in 1995 and increased into the upper quartile again in 1998-2001 (Table 10).

This suggests that the plant community in Long Lake has been cycling in its closeness to an undisturbed condition. This is likely due to cyclic disturbance in Long Lake. More recently, it appears that Long Lake is recovering from disturbance.

Disturbances can be of many types:

1) Biological disturbances include the introduction of a non-native or invasive plant species, grazing from an increased population of aquatic herbivores and destruction of plant beds by the fish population.
2) Direct disturbances to the plant beds result from activities such as boat traffic, plant harvesting, chemical treatments, the placement of docks and other structures and fluctuating water levels.
3) Indirect disturbances can be the result of factors that impact water clarity and thus stress species that are more sensitive: resuspension of sediments, sedimentation from erosion, increased algae growth due to nutrient inputs.

IV. DISCUSSION

Based on water clarity and concentration of algae and nutrients, Long Lake has been a mesotrophic/oligotrophic lake with good water clarity and very good water quality during the study period (1986-2001). Lakes in this trophic range should have low to intermediate amounts of biomass. The relatively small watershed to lake ratio (<4:1) is one factor in preserving the good water quality. In addition, a large portion of the watershed is protected by forest and wetlands (87%).

Since 1986, the phosphorus (nutrients) has increased slightly, the chlorophyll (algae) has decreased and the water clarity has decreased. Chlorophyll was at the lowest concentrations recorded in 2001-2002.

Long Lake has a protecting buffer of native plant growth (wooded, shrub and native herbaceous). However, natural shoreline has decreased, especially shrub cover. Natural cover at the sites has decreased from 87% cover in 1995 to 80% cover in 2001. Conversely, disturbed shoreline has increased since 1995, from 13% coverage in 1995 to 20% coverage in 2001. Cultivated lawn alone increased from 9% to 13% coverage and occurs at one-third of the sites. Cultivated lawn can contribute added nutrients and toxic chemicals from run-off of pet waste and lawn chemicals.

Aquatic macrophyte community

Plant growth in Long Lake is sparse (only 6-15% of the sites supported vegetation) and is limited to the 0-5ft depth zone. A combination of factors may be contributing to the sparse growth of aquatic plants: the lake's oligotrophic/mesotrophic status, the soft water, the steeply sloped littoral zone in nearly half the lake, the dominance of high-density sand and rock sediments, herbivory by rusty crayfish and layers of peat on the lake bottom.

Although vegetation is sparse Long Lake, the aquatic plant community has very good diversity. The quality of the aquatic plant community in Long Lake increased in 2001 and is of nearly average for Wisconsin lakes as measured by the AMCIndex. The quality of the aquatic plant community is limited by the sparse growth, especially submergent plant growth. The actual maximum rooting depth had been much less than the predicted maximum rooting depth, based on water clarity until 2001 when small rosette plant species were surveyed at 15 feet.

The Average Coefficients of Conservatism and Floristic Quality indices (FQI) indicate that the aquatic plant community in Long Lake is average for Wisconsin and Region lakes in its disturbance tolerance and closeness to an undisturbed condition.

Change in the macrophyte community

The low Coefficients of Community Similarity indicate that the composition of the aquatic plant community is significantly different in each survey. The dominant species, most frequently occurring species and the species recorded at the maximum depth have changed in very study throughout 1986-2001.

Nuphar variegata was dominant in 1986
Pontederia cordata was dominant in 1986 and 1992
Potamogeton amplifolius was dominant in 1989
Elodea canadensis was the dominant species in 1995
Pontederia cordata was the dominant species again in 1998
Scirpus validus was dominant in 2001.

This suggests a cyclic nature of the plant community.

The Average Coefficients of Conservatism and Floristic Quality indices (FQI) indicate that the aquatic plant community in Long Lake has cycled in its disturbance tolerance and closeness to an undisturbed condition.

Other measures of the aquatic plant community have shown a cyclic pattern in Long Lake:

Number of species recorded
Simpson's Diversity Index
Floristic Quality (disturbance)
Percent coverage of vegetation
Percent coverage of emergent species
Occurrence of filamentous algae (4-17%)

In 1986 and 1989, the aquatic plant community appeared to be at its lowest:

1) the lowest percentage of vegetated sites (including the lowest coverage of submergent species and emergent species)
2) the lowest total occurrence of aquatic plants
3) the lowest total density of aquatic plants
4) the lowest number of species
5) the lowest species diversity
6) the lowest Floristic Quality Index (highest disturbance).

In 2001, the aquatic plant community appeared to be at its highest:

1) the highest percentage of vegetated sites (including the greatest coverage of emergent species)
2) the greatest number of species
3) the highest species diversity
4) the maximum rooting depth had increased dramatically
5) the highest Floristic Quality Index (lowest disturbance).

Although the plant community and the measurements of the community have cycled up and down, overall, from 1986 to 2001, all parameters measuring the aquatic plant community have increased, except for the coverage of floating-leaf vegetation and free-floating vegetation. The coverage of floating-leaf vegetation has remained fairly stable. The coverage of submergent vegetation at the sample sites has increased the most, a five-fold increase.

Reasons for change in the plant community

Residents on Long Lake noticed that the decline of the aquatic plant community coincided with an increase in the rusty crayfish population. The 1986 plant survey recorded the lowest abundance and quality of aquatic plant growth during the Long Term Trend Study. The rusty crayfish population started declining after the 1986 plant survey. The 1992 aquatic plant survey recorded greater abundance of plant growth. This cycling of aquatic plants is similar to the cycles Saiki and Tash (1979) recorded in their study of the interaction of rusty crayfish populations with aquatic plant communities.

A 1974 Long Lake crayfish study found that the density of rusty crayfish at sampling sites was inversely proportional to the density of aquatic plant growth at the same sites and, based on food requirements of the rusty crayfish, the population densities of rusty crayfish in Long Lake were sufficient to eliminate the aquatic vegetation (Magnuson et. al. 1975).

The frequency and density of aquatic plants and the quality of the plant community may cycle up and down as the rusty crayfish population goes through cycles of increase and decline (Magnuson et. al. 1975).

Layers of peat, or detritus (undecomposed plant material), were found at many transects and could prevent plant growth via a smothering effect or by the flocculent nature of peat that is not conducive to the permanent rooting of plants. An increase in peat layers is usually found in the natural succession of bog ecosystems (Cairns & Sorge 1978).

Comparison with Earlier Surveys

The survey conducted by Environmental Resource Assessments in 1977 (Cairns and Sorge 1978) employed different methods than the DNR studies, therefore, it would be inappropriate to directly compare the 1977 data to the 1986-1998 studies. However, some general findings are in agreement with the later Long Term Trend findings: percent coverage of vegetation, maximum rooting depth, depth zones with the greatest amount of vegetation, species recorded, prevalent species and percent occurrence of species.

V. CONCLUSIONS

Long Lake is an oligotrophic/mesotrophic lake with good water clarity and very good water quality. Since 1986, nutrients have increased in Long Lake; water clarity has decreased; but algae have decreased. The small watershed in relation to the size of the lake is and natural cover in the watershed is a major factor in preserving water quality; most nutrient inputs would come from shoreline properties.

The aquatic plant community in Long Lake is of slightly below-average quality for Wisconsin lakes, yet Long Lake's plant community has very good species diversity. The below average quality is due to sparse plant growth. Plants were found in scattered beds, mostly limited to the 0-5ft depth zone.

Several factors could limit aquatic plant growth in Long Lake:

1) high-density, hard sediments (sand and rock)
2) steeply sloped littoral zone
3) limited nutrients of oligotrophic lakes
4) the soft water
5) herbivory by rusty crayfish.

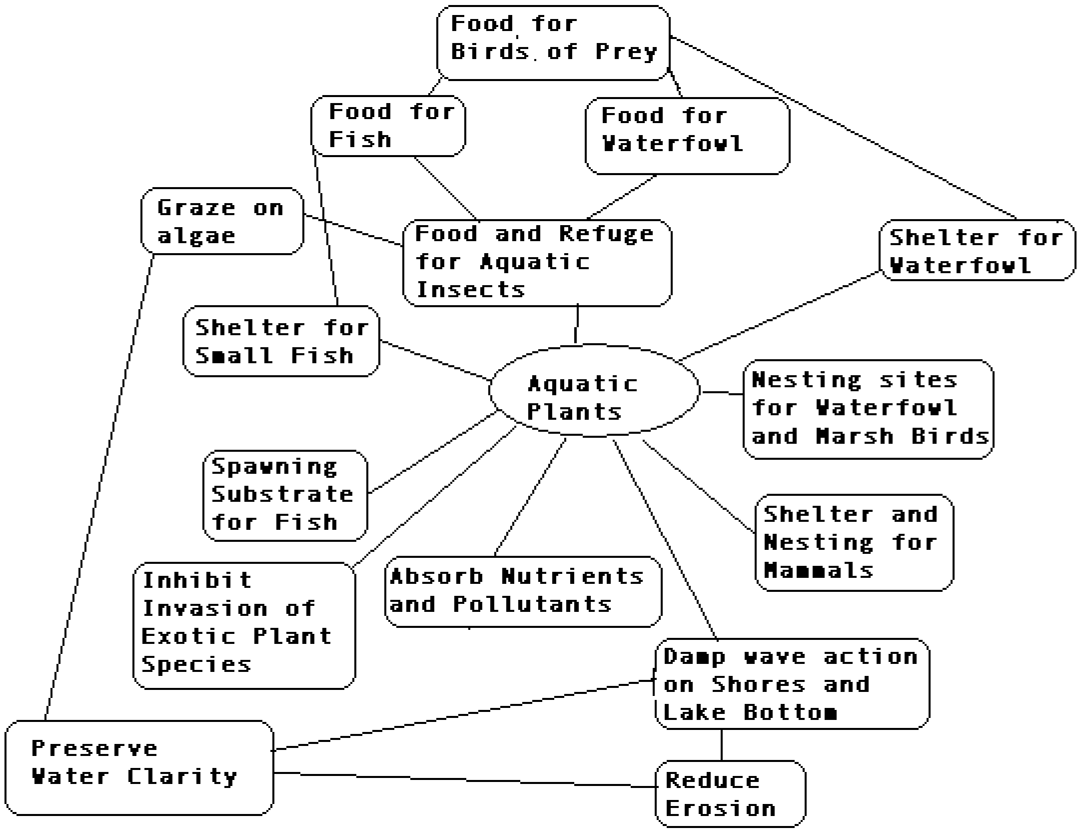
There are several pieces of evidence that rusty crayfish are at least one factor in the sparse aquatic plant growth in Long Lake.

1) The cycling of aquatic plant community in its abundance and quality. The composition of the aquatic plant community has been significantly different in each study and the dominant species change every year. The number of species, the diversity index, the disturbance index and the percent coverage of vegetation have all been cyclic.
2) The 1974 study of the crayfish population found that the areas of Long Lake with the lowest coverage of plant growth were also the areas with the densest populations of rusty crayfish (Magnuson et. al. 1975).
3) The estimated size of the rusty crayfish population in Long Lake (Magnuson et. al. 1975) and the estimated food requirement of that population is sufficient to decimate the plant beds in Long Lake (Miller et. al. 1989).

The 2001 aquatic plant community in Long Lake has the greatest amount of and highest quality of plant growth. Coverage of submergent vegetation has increased 5-fold since 1986.

Importance of aquatic plant communities

A healthy aquatic plant community plays a vital role within the lake community. This is due to the role plants play in 1) improving water quality 2) providing valuable resources for fish and wildlife 3) resisting invasions of non-native plant species and 4) checking excessive growth of more tolerant species that could crowd out other species, reducing diversity.



1) Aquatic plants improve water quality in many ways: they trap nutrients, debris, and pollutants entering a water body; they may absorb and break down the pollutants; they reduce erosion by damping wave action and stabilizing shorelines and lake bottoms; they remove nutrients that would otherwise be available for algae blooms (Engel 1985).
2) 2) Aquatic plant communities provide important fishery and wildlife resources. Aquatic plants and algae start the food chain that supports many levels of wildlife, and at the same time produce oxygen needed by animals. Plants are used as food, cover and nesting/spawning sites by a variety of wildlife and fish. Compared to non-vegetated lake bottoms, aquatic plant beds support larger, more diverse invertebrate populations (Engel 1985; Crowder and Cooper 1979); that in turn will support larger and more diverse fish and wildlife populations (Wiley et. al. 1984). Sparse plant growth supports fewer prey fish, while dense plant growth is overly protective of the prey fish by limiting the success of predatory fish.

An intermediate density of aquatic plants promotes better growth rates in fish than either high of low density (Crowder and Cooper 1979). Some studies have suggested optimal coverage of plants, 36% cover over the entire water body (Wiley et. al. 1984). Aquatic plants in Long Lake provide 6-15% cover within the littoral zone. This is much less than the suggested optimal coverage of aquatic plants and is even less when calculated over the entire lake surface.

Recommendations for lake association management

1) Cooperate with efforts to protect the natural landscape in the watershed
2) Encourage lake residents to preserve the natural vegetation along the lakeshore. Much of the shoreline around Long Lake is protected by natural plant cover, but the amount of disturbed shoreline has increased since 1995. The mean coverage of disturbed shoreline (lawns, hard structures, bare soils, and pavement) has increased from 13% in 1995 to 20% in 2001. A decrease in shrub cover has accompanied the increase in cultivated lawn.
3) Encourage lake residents to replace natural shoreline in areas that have been converted to cultivated lawn. Replacing shrub cover would also enhance wildlife habitat.
4) Assess septic systems along the lakeshore to insure that septic systems are not contributing nutrients that would speed the eutrophication of Long Lake.
5) Conduct studies designed to determine the impact of the rusty crayfish in Long Lake on the aquatic plant community in Long Lake.
6) At present, there is no environmentally sound, effective way known to control or eliminate rusty crayfish (Gunderson 1995). Research literature regarding studies on rusty crayfish control and experiment with control methods in Long Lake
7) Help ensure the preservation of the sensitive areas designated on Long Lake.
8) Continue volunteer water quality monitoring

Department of Natural Resources Recommendations

1) Increase aquatic plant study transects on Long Lake to 31 by randomly placing 4 additional transects.
2) Continue water quality monitoring.